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NRL Extreme Ultraviolet and Soft X-Ray Calibration Facility at the National Synchrotron Light Source

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The Naval Research Laboratory (NRL) has developed a calibration facility for the extreme ultraviolet and soft x-ray wavelength regions (12 Å to 2000 Å). The beamline at Brookhaven's National Synchrotron Light Source (NSLS) provides monochromatic radiation which can be scanned in wavelength under computer control. Several calibration chambers can be used for the calibration of instrument components and the end-to-end calibration of complete instruments. The components and instruments are easily manipulated to provide a wide variety of calibration data.

Synchrotron Beamline

NRL has constructed the beamline X24C that is attached to the NSLS x-ray ring as shown in Fig. 1. The beamline's monochromator has two elements that are scanned under computer control while keeping the entrance and exit slits fixed. Each monochromator element is selectable and can be a diffraction grating, a crystal, or a mirror. The various elements are mounted on two carousels that are rotated into position. For example, if dispersed EUV radiation is desired, the two selected elements would be a grating and a gold mirror. The grating and the mirror then move under computer control so that dispersed radiation of a known wavelength passes through the exit slit and into the calibration chamber.

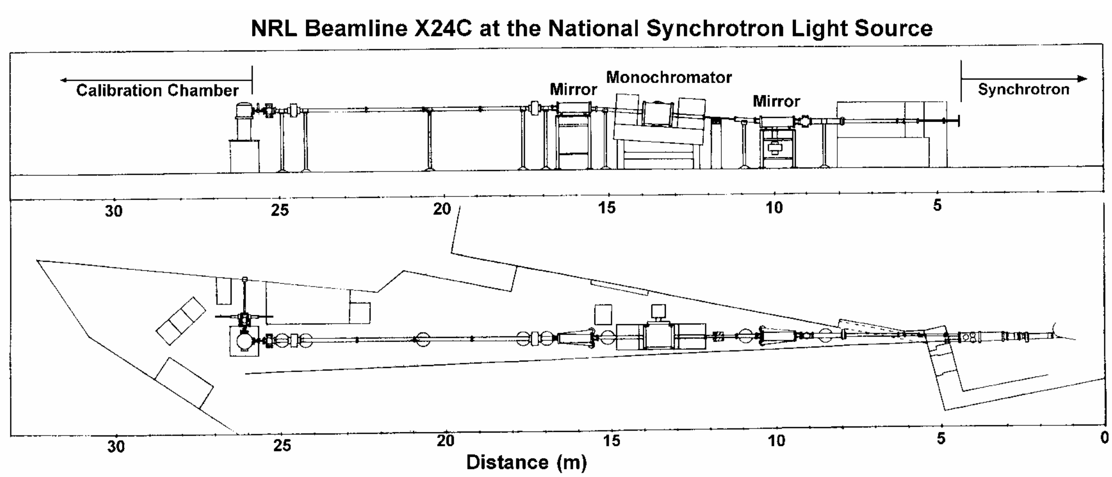


Fig. 1. The NRL beamline X24C attached to the NSLS x-ray ring.

Gratings with 150 g/mm, 600 g/mm, and 2400 g/mm are available. The overall range of coverage of the gratings is approximately 12 Å to 2000 Å. The resolving power, spectral range, and flux delivered to the calibration chamber depend on the wavelength and the monochromator elements that are selected. The resolving power is approximately 400 when the 600 g/mm grating and a gold mirror are utilized. Typical fluxes delivered to the calibration chamber are shown in Table 1. Various filters, mounted on a linear translation bar, may be moved into the beam for the purpose of suppressing higher-order radiation from the monochromator. The radiation is highly polarized (90%) with the electric field vector in the horizontal plane.

Table 1. Typical X24C beamline fluxes.

Photon Energy (eV)A	Wavelength (nm)A	Filter	Transmittance (%)B	Detector Current (nA)C	Responsitivity (A/W)D	Observed Flux (10^10 ph/sec)E
140.0	8.9	Zr 1020	50	171	0.23	3.3
40.0	31.0	Al/Mg/Al	24	64	0.22	4.5
20.0	62.0	Sn 1000	29	7.6	0.16	1.5
14.0	88.6	In 1000	4	5.4	0.096	2.5
10.2	121.6	LiF	50	0.36	0.122	0.2

Except for the 10.2 eV data, the monochromator conditions are minimum stairstep baffle, 400 micron slit, G1=Au mirror, G2=600L/mı
For the 10.2 eV data, the monochromator conditions are the same except G1=Si mirror, G2=150L/mm.

Notes
A Beamline photon energy (eV) and wavelength (nm).
B Ratio of the beamline flux without and with the filter. The LiF transmittance was measured by Panametrics.
C Observed detector current flux with the filter.
D IRD silicon detector responsitivity (NIST).
E Observed beamline flux through the filter derived from the detector current and responsitivity.

The minimum beam divergence is approximately 1 mrad in the vertical direction and adjustable over the range of 1 to 6 mrad in the horizontal direction (defined by a beam-limiting aperture). The size of the beam varies from 1 mm to 3 mm depending on the distance from the monochromator's exit slit, the slit width, and the width of the beam-limiting aperture.

Strict UHV beamline cleanliness and contamination procedures are followed. The typical base pressure in the beamline is $2x10^{-9}$ Torr or lower.

Reflectometer

A photograph of the reflectometer, the photodiode chamber, and the larger instrument calibration chamber attached to the beamline is shown in Fig. 1. Smaller instrument components such as gratings, filters, and sensors can be calibrated in the reflectometer and the photodiode chamber. Large components and complete instruments can be calibrated in the larger calibration chamber.

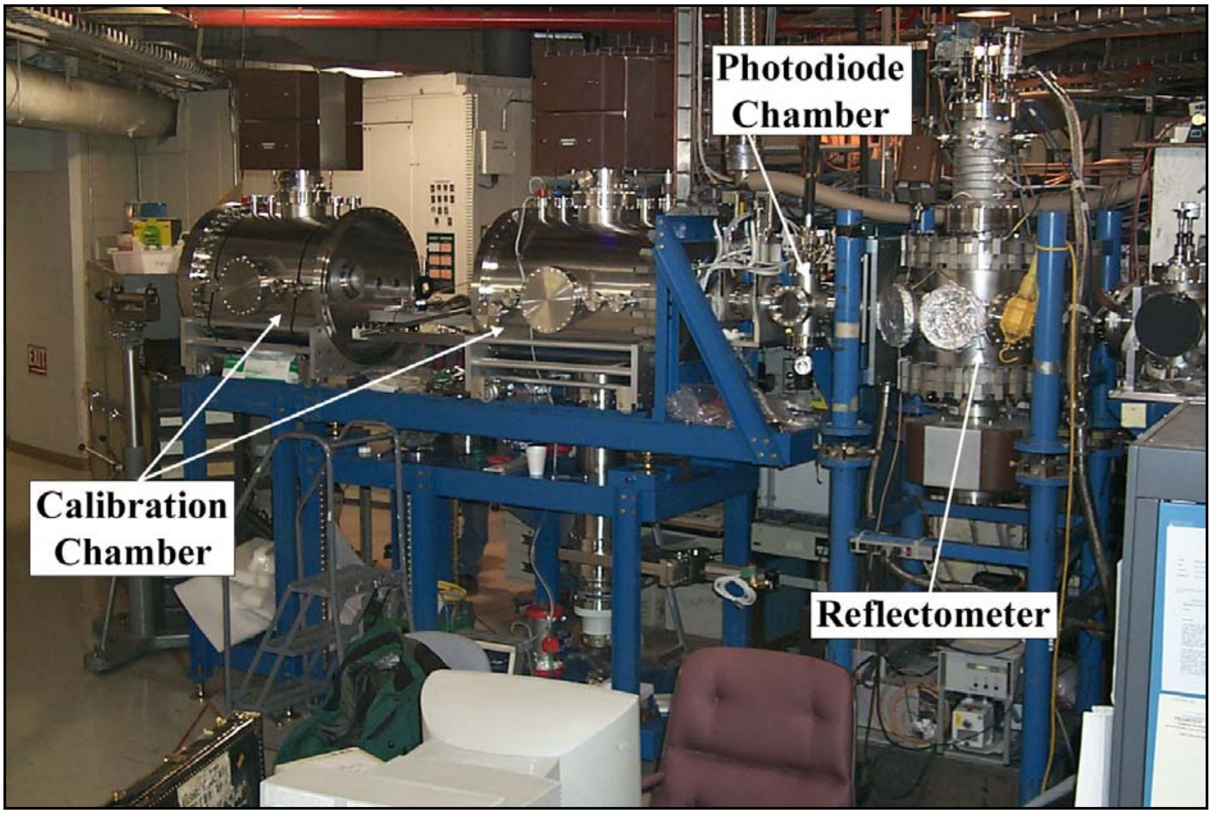


Fig. 2. Calibration chambers attached to the X24C beamline.

The internal motions of the reflectometer are shown in Fig. 3. The small sample (such as a grating or filter) is mounted on the rotational axis and is precisely rotated to change the angle of incidence. The detector can be rotated in azimuthal angle about the sample and in altitude. The angular motions are performed under computer and are accurate to 0.05^{o}. The entire reflectometer chamber can be rotated from the vertical orientation to the horizontal orientation to measure the sample response in the orthogonal polarization. The pressure in the reflectometer is typically less than 10^{-7} Torr.

The photodiode chamber has a translational fixture that can hold up to six sensors. The sensor currents are measured by a precision Keithley electrometer and saved in a computer file. The sensor response can be related to the current from a silicon photodiode with absolute responsivity traceable to NIST.

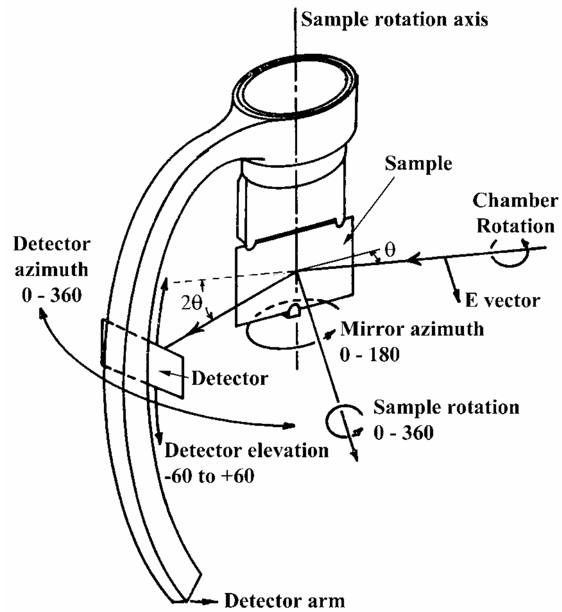


Fig. 3. Schematic of the reflectometer internal motions.

Instrument Calibration Chamber

The NRL Space Science Division has developed a vacuum chamber that is suitable for the calibration of complete instruments. The dimensions of the chamber are shown in Fig. 4. This chamber has been utilized for the calibration of NASA and NOAA instruments.

The chamber is cylindrical in shape with an ID of 23.75" and a length of 63.0". The synchrotron radiation enters through a port (3.81" ID) that is centered on the front end plate. One of several different instrument mounting fixtures may be positioned in the chamber and suspended from the front end plate. This allows the rear cylinder to be rolled back for access to the instrument as illustrated in Fig. 2. A clean tent is available for use when the cylinder is rolled back.

One instrument mounting fixture is a table (15.75" wide and suspended from the front plate) that extends the length of the chamber. On this table are three slides that support an optical bench. The optical bench can be moved horizontally up to 6" (depending on the size of the instrument) by means of a manipulation rod. Mounted on the optical bench is an axial rotation stage centered at the height of the chamber axis that is at a distance of 6.88" above the table. Instruments may be mounted on the axial rotation stage, the optical bench, the slides, or the table depending on the requirements for rotational and horizontal motions and on the instrument size.

The chamber has four 10" CF window ports that provide instrument viewing and access without rolling back the rear cylinder. A number of 2.75" CF ports provide for electrical and mechanical feedthroughs.

A NASA/GSFC Cassegrain telescope with two multilayer-coated mirrors is shown in Fig. 5 mounted on the rotational stage. A NOAA transmission grating spectrometer mounted on another stage with x, y, and yaw (ϕ) motions is shown in Fig. 6.

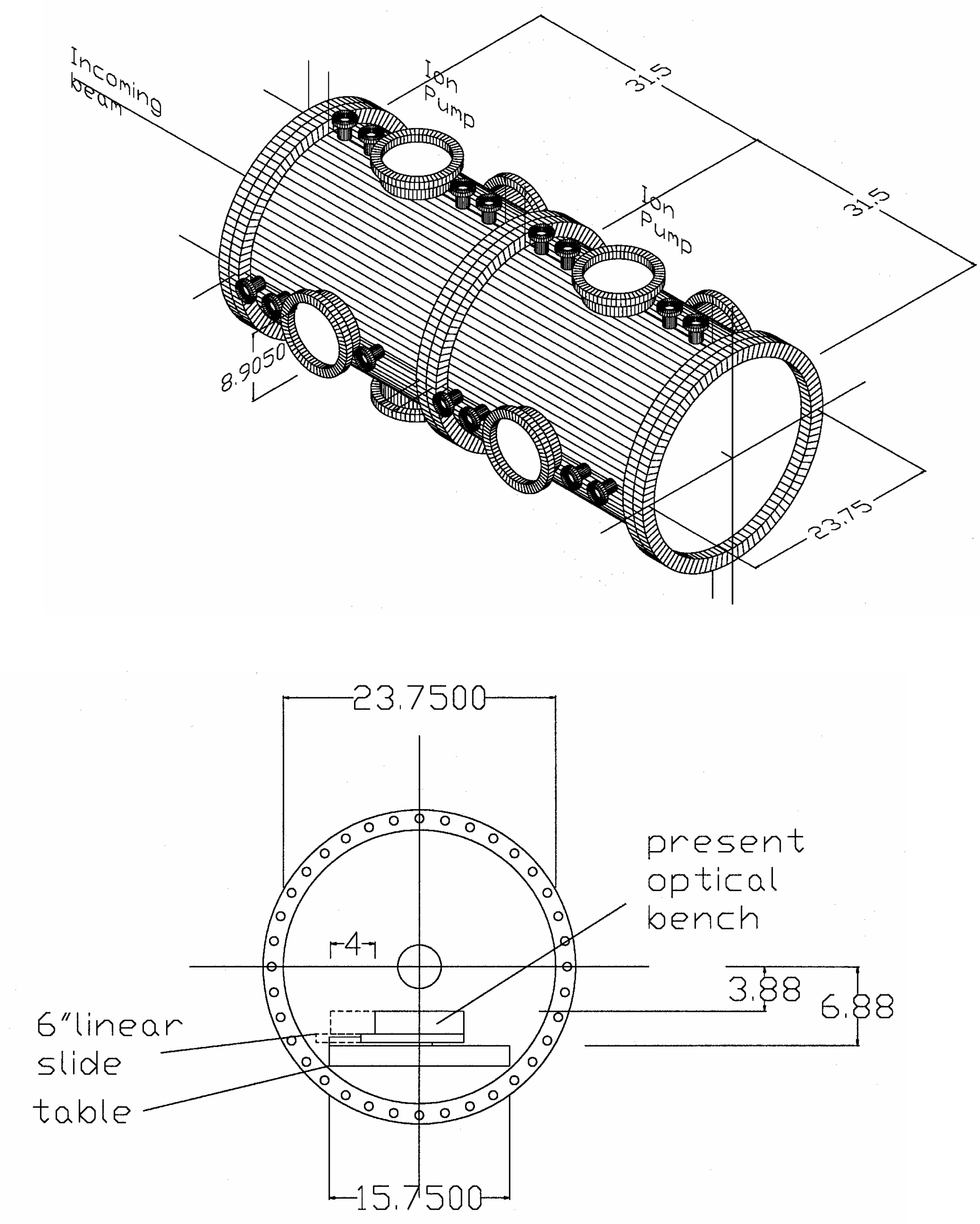


Fig. 4. Dimensions of the instrument calibration chamber and the optical bench and rotational stage.

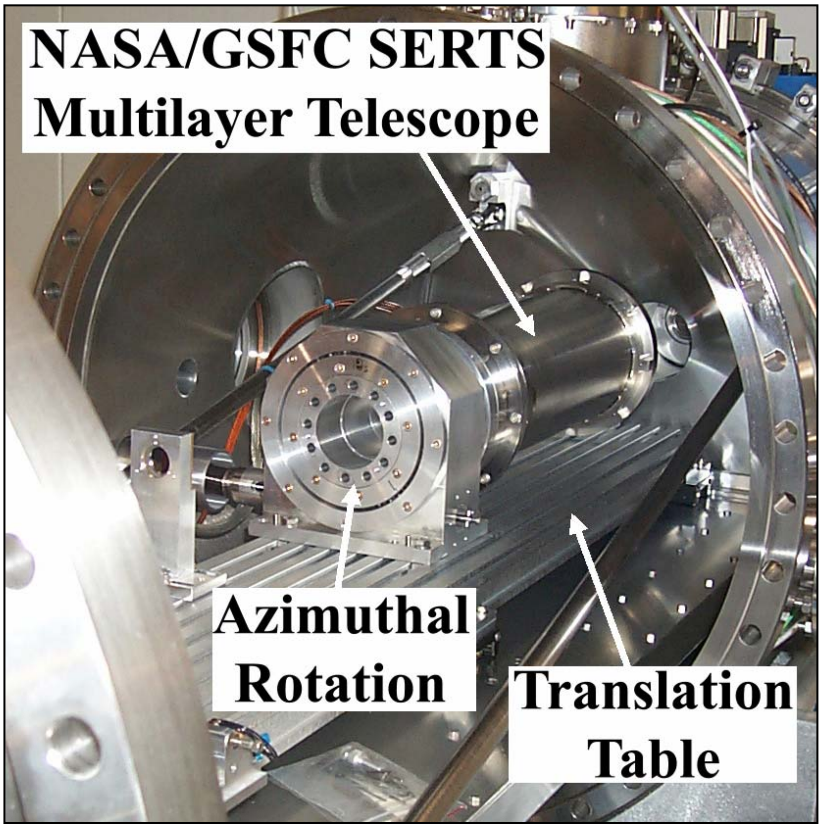


Fig. 5. Cassegrain telescope mounted in the instrument calibration chamber on the rotational stage.

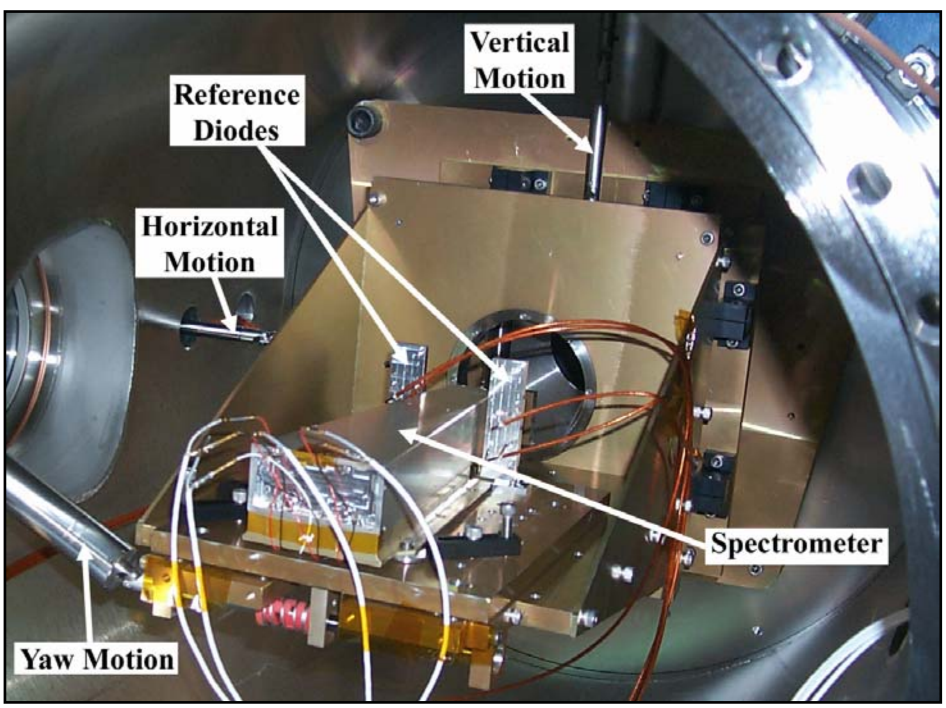


Fig. 6. NOAA transmission grating spectrometer mounted in the instrument calibration chamber on the xyϕ stage.

An optic mount is available that can hold a mirror or grating up to 10” in size. Shown in Fig. 7 is a 6” mirror with a multilayer coating that was developed for the NASA Extreme Ultraviolet Imaging Spectrometer (EIS). The optic mount is positioned in the rear of the calibration chamber, and a detector arm is positioned near the axial mid-point of the chamber. The optic can be precisely moved under computer control in x, y, and angle of incidence. The detector can be precisely moved along an arc in the horizontal plane (varying the angle of reflection or diffraction) and also vertically.

A gate valve, turbo pump, and oil-free backing pump are suspended from a 12” CF port on the bottom of the instrument calibration chamber. Two ion pumps are positioned on two 10” CF ports on the top of the chamber. With a typical space instrument in the chamber, the pressure is approximately 10^{-6} Torr or lower after 24 hours of pumping, depending on the cleanliness of the instrument.

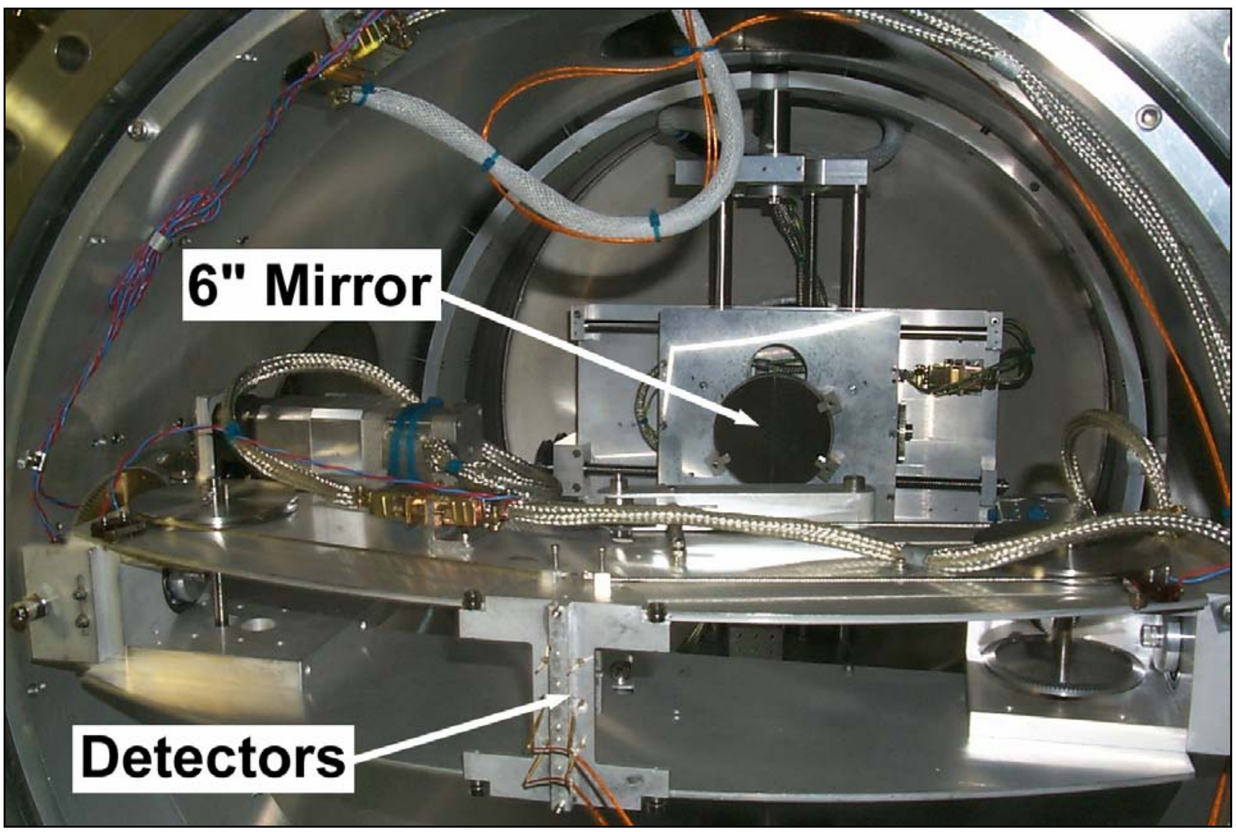


Fig. 7. The 6” EIS multilayer-coated mirror mounted in the calibration chamber.

Two gate valves are attached to the chamber's entrance port for the purpose of isolating the calibration chamber from the UHV synchrotron beamline. The valve closest to the port has a holder for a thin transmission filter, and the valve just upstream has a sapphire window. When the window valve is closed and the filter valve is open, the instrument can be aligned to the visible light beam that is transmitted by the sapphire window. The visible light beam travels the same path as the EUV dispersed beam from the monochromator. With the chamber under vacuum, the filter valve may be closed, thus inserting the filter in the beam path, and the sapphire valve opened. Measurements are performed with EUV radiation that is dispersed by the beamline's monochromator and transmitted by the filter. Before the chamber is vented, the sapphire valve must be closed and the filter valve opened. Thus the calibration chamber is never fully open to the beamline, as required by beamline UHV vacuum and cleanliness guidelines.

The thin filter in the filter valve may be changed by removing the gate from the VAT valve. The filter ring is a standard size, and various EUV filters are available from commercial vendors, for example Luxel Inc.

In addition to the filter valve, EUV and x-ray transmission filters are mounted on a translation fixture, located between the two gate valves, that can hold six filters. This filter fixture provides differential pumping that isolates the calibration chamber from the beamline when the filter gate valve is open. Selectable filters are available that can be used for calibration measurements throughout the 12-2000 Å wavelength range.

The calibration chamber has a dedicated Residual Gas Analyzer (RGA) and a Thermoelectric Quartz Crystal Microbalance (TQCM) to monitor the vacuum conditions. A clean tent is available for use when venting the chamber for insertion and removal of instruments or components.

Typical Calibrations

Shown in Fig. 8 is the measured near-normal-incidence reflectance of a Mo/Si multilayer mirror in the 125-150 Å wavelength region and in the two orthogonal polarizations. The measurements are in excellent agreement with the calculated reflectances. Shown in Fig. 9 are the reflectances of Sc/Si multilayer mirrors with tungsten barrier layers measured in the 400 Å region.

The efficiency of a 2400 g/mm grating with a MoRu/Be multilayer coating measured at a wavelength of 113.7 Å and an angle of incidence of 13.9^{o} is shown in Fig. 10. The normal-incidence efficiency of a 5000 L/mm transmission grating measured for incident wavelengths of (a) 88.6 Å and (b) 304 Å is shown in Fig. 11.

The normal-incidence transmittances of aluminum coatings on silicon photodiodes are shown in Fig. 12. The absolute responsivities of the diodes were measured by comparison to a silicon photodiode traceable to NIST.

Figure 13 (Top) shows the signal from a 1 mm^2 silicon photodiode observed from the 25 electron bunches circulating in the storage ring and for an incident wavelength of 177 Å (70 eV). The signal was measured using an oscilloscope with 1 GHz bandwidth and 5 GHz sampling. Figure 13 (Bottom) shows the signal from one electron bunch and indicates the risetime and falltime of the diode signal.

Measurements at small grazing angles can be accomplished by mounting the optic on a precision goniometer with computer controlled motions. Shown in Fig. 14 is a grating, patterned on a 4” silicon wafer, mounted in the two polarization orientations, horizontal (TM, electric vector approximately parallel to the grating surface) and vertical (TE, electric vector perpendicular to the surface). This is a 5000 L/mm test grating for the *Constellation-X* mission produced at MIT. The diffraction pattern is recorded by a CMOS imager with 2” square area. Shown in Fig. 15 is the conical diffraction pattern from the MIT grating when in the off-plane (conical) TM orientation.

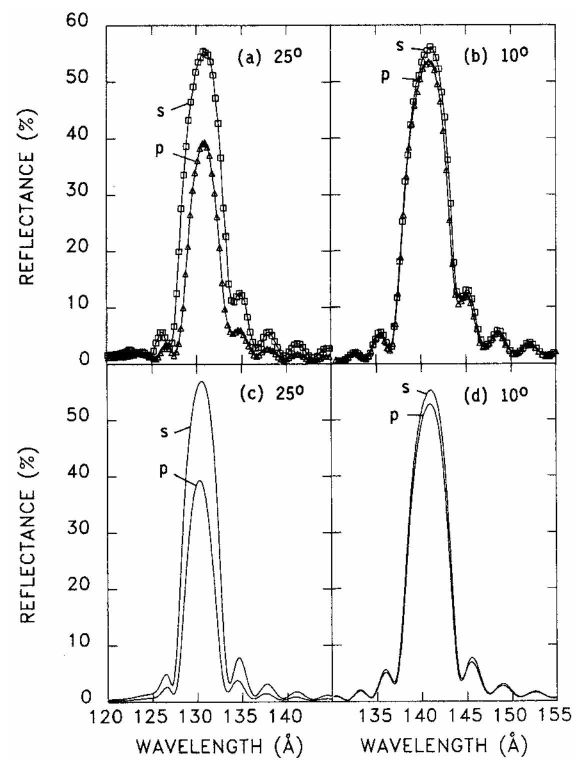


Fig. 8. (a) and (b) are the measured reflectances of a Mo/Si coating at angles of incidence of 25^{o} and 10^{o}. (c) and (d) are the calculated reflectances. The two polarizations of the incident radiation are indicated.

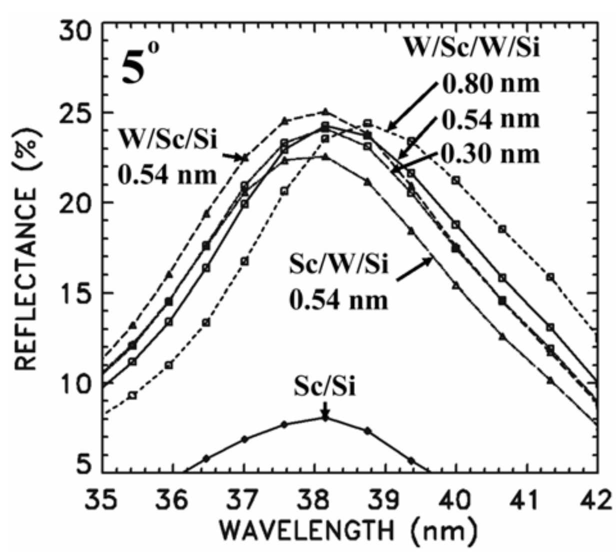


Fig. 9. The reflectance of Sc/Si multilayer mirrors with tungsten barrier layer of various thicknesses measured at an angle of incidence of 5^{o}.

Fig. 10. The efficiency of a 2400 gr/mm grating with a MoRu/Be multilayer coating measured at a wavelength of 113.7 Å and an angle of incidence of 13.9°. The outside (m<0) and inside (m>0) diffraction orders are identified.

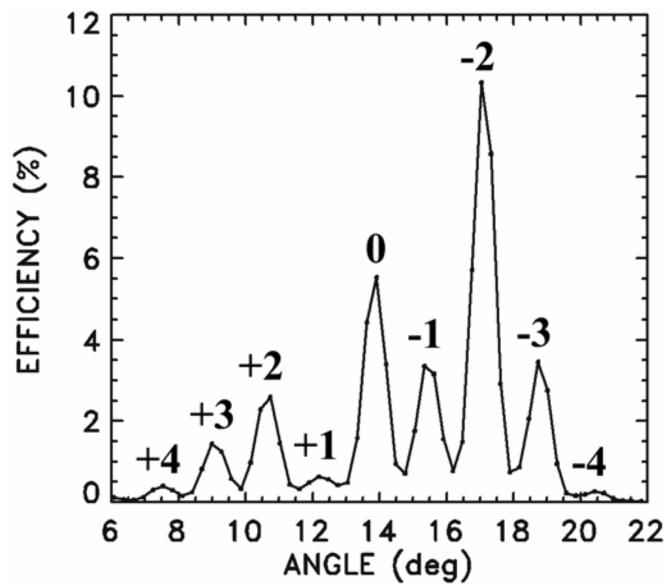
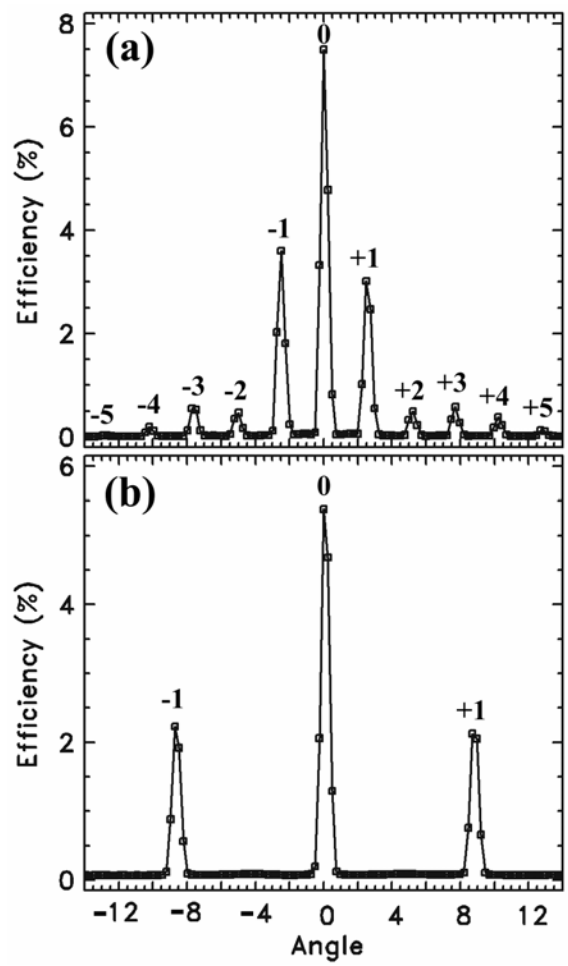


Fig. 11. The normal-incidence efficiency of a 5000 L/mm transmission grating measured for incident wavelengths of (a) 88.6 Å and (b) 304 Å. The diffraction orders are indicated.



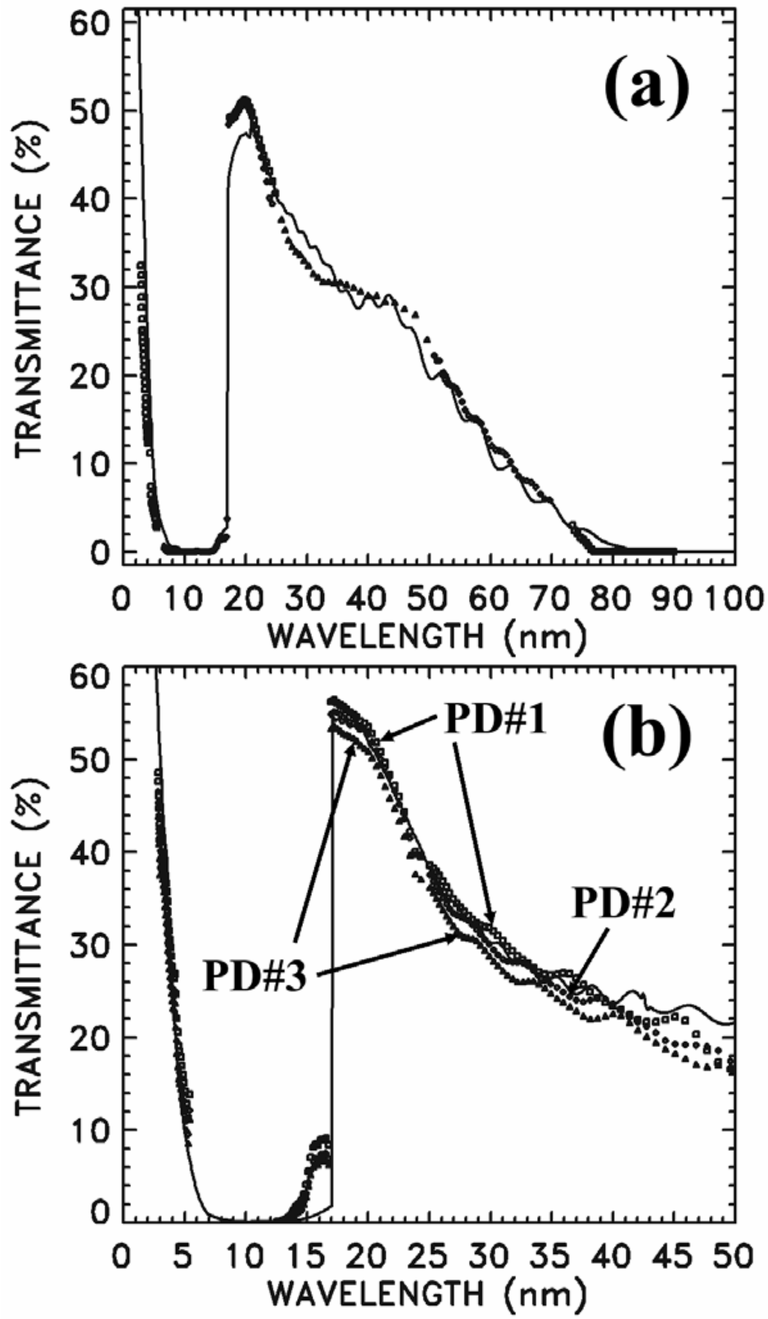


Fig. 12. (a) The measured transmittance of an aluminum coating on a photodiode (data points) and the calculated transmittance of an aluminum coating with 200 nm thickness (curve). (b) The measured (data points) and the calculated (curve) transmittances of the aluminum coatings on three photodiodes.

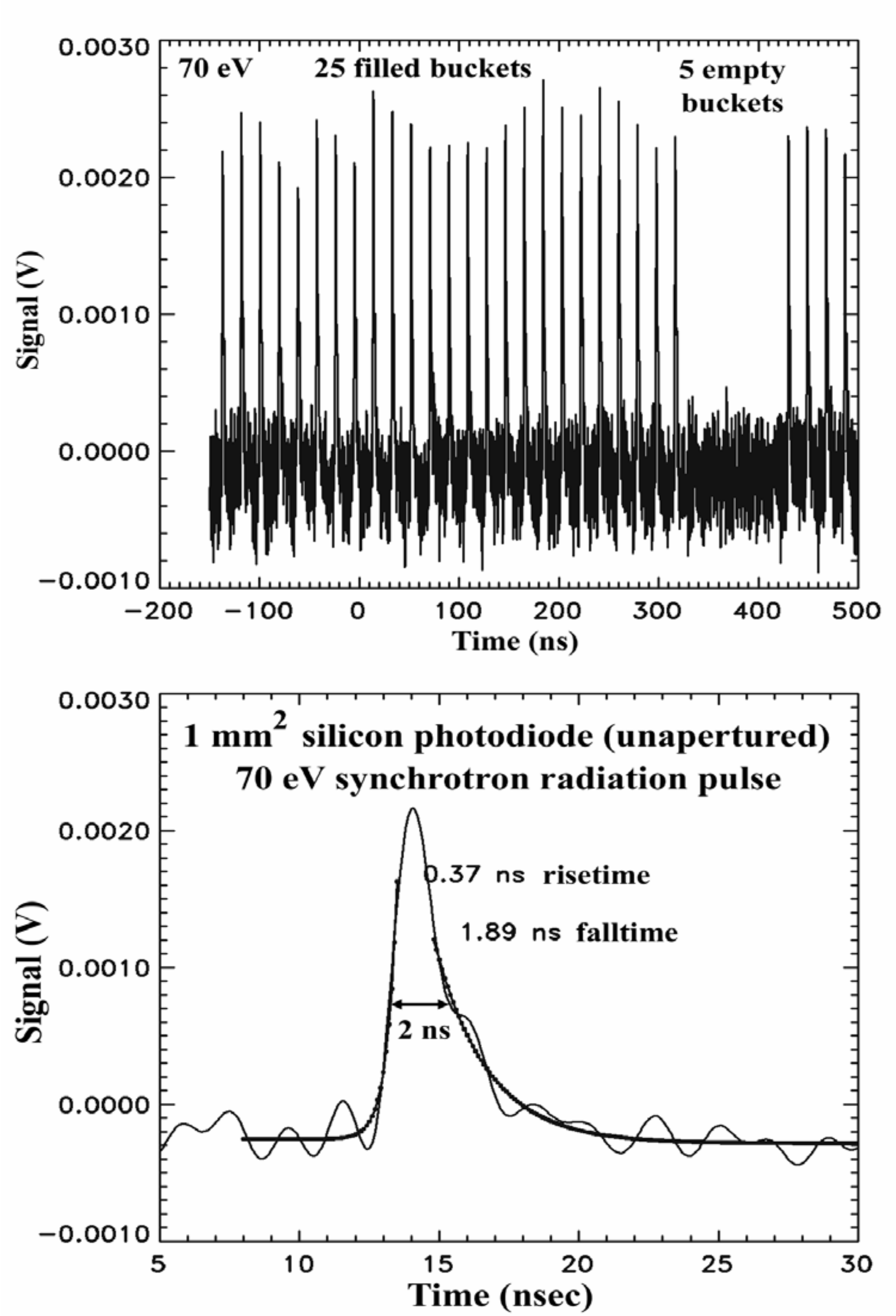


Fig. 13. Top: The signal from a 1 mm^2 silicon photodiode observed from the 25 electron bunches circulating in the storage ring and for an incident wavelength of 177 Å (70 eV). Bottom: The single-bunch pulse from the diode.

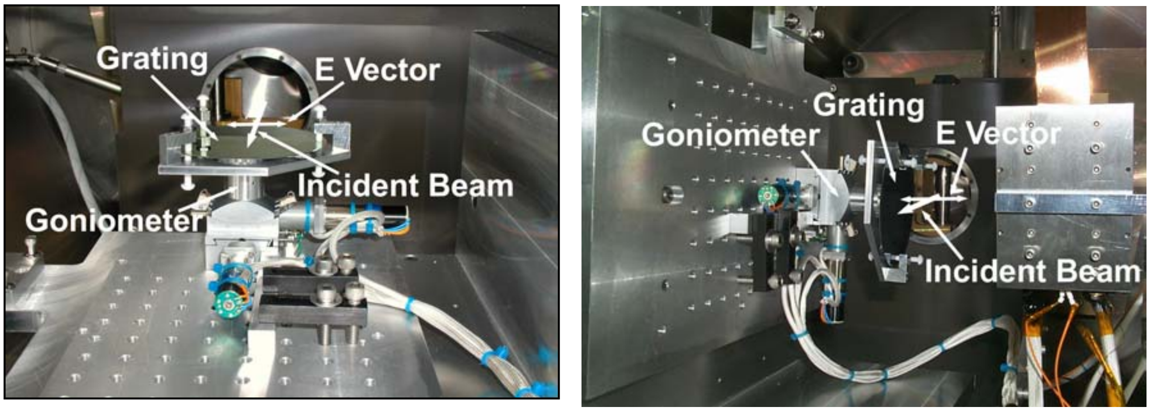
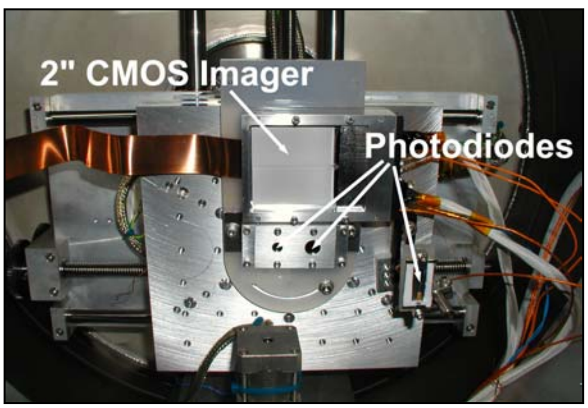


Fig. 14. The MIT *Constellation-X* test grating in the TM (left) and TE (right) orientations.



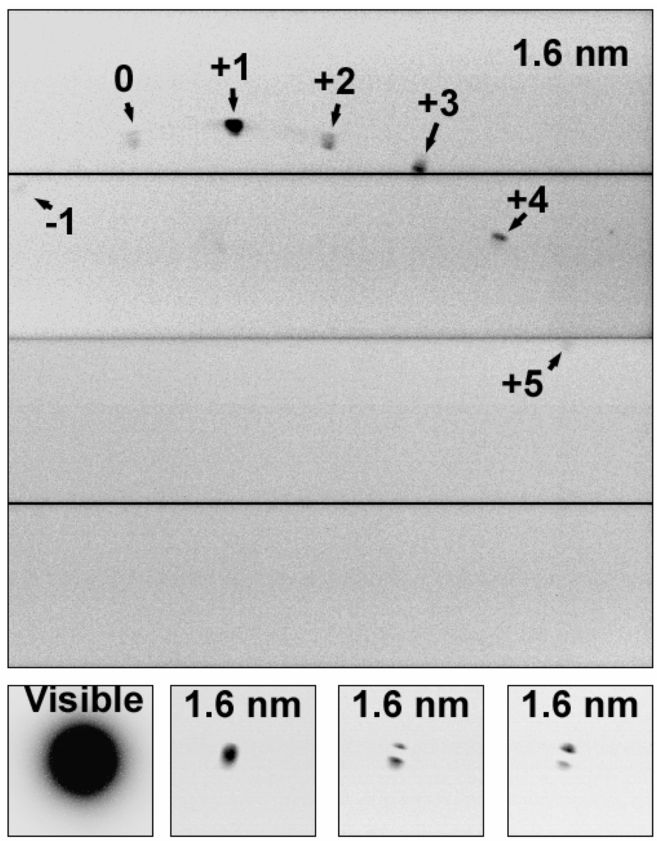


Fig. 15. Above: CMOS imager and three photodiodes mounted on the detector plate. Right: CMOS image of the conical diffraction pattern for a wavelength of 1.6 nm. Shown below the CMOS image are subimages of the visible light beam and the 1.6 nm beam. The two subimages of the shadow of the grating in the 1.6 nm beam, shown at the lower right, illustrate how rapid feedback from the CMOS images can be used to establish grating alignment under x-ray